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9 # Safety Evaluation Tests of Personal Protective Equipment for Ordnance Operations.

by


10 Glenn C. Pritchard

Safety and Security Department


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Naval Weapons Center

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## FOREWORD

This report summarizes the results of tests conducted at the Naval Weapons Center (NWC) to evaluate the effectiveness of personal protective equipment used by personnel involved with the processing, testing, and storing of high-energy materials.

The work covered by this report was funded by Safety and Security Department overhead funds and by Ordnance Systems Department safety overhead funds.

This report is released for information only. Protective equipment described herein was purchased for limited applications and use by NWC personnel. NWC assumes no responsibility for an action or incident resulting from the use of the equipment by other than NWC personnel.

The use of the trade names in this report is for identification purposes only and does not constitute an endorsement of the products so named.

This report was given technical review by Paul A. Donaldson of the Safety and Security Department.

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1 February 1978

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(U) *Safety Evaluation Tests of Personal Protective Equipment for Ordnance Operations*, by Glenn C. Pritchard. China Lake, Calif., Naval Weapons Center, August 1978. 38 pp. (NWC TP 6008, publication UNCLASSIFIED.)

(U) This report presents and summarizes the results of tests conducted at the Naval Weapons Center to study the effectiveness of personal protective equipment used in operations involving propellants, explosives, pyrotechnics, and other high-energy materials. Criteria used to evaluate the equipment and the limitations of each type of equipment are discussed. Variables to be controlled or included in future tests are also discussed.

## CONTENTS



## ACKNOWLEDGMENT

The safety clothing test was conducted by James P. Diebold of the Ordnance Systems Department. Portions of his unpublished data are included herein.

The conductivity test using various sock types was conducted by Paul A. Donaldson and Edgar A. McDuff of the Safety and Security Department. Portions of their unpublished data are included herein.

## INTRODUCTION

Current explosives safety regulations (Appendix A) require the use of personal protective equipment where work involves the processing, testing, or handling of hazardous materials, such as propellants, explosives, pyrotechnics, and initiating devices. The regulations are intended either to preclude the accidental ignition of high-energy materials or, should ignition occur, to minimize the resultant injury to operating personnel by providing the necessary protection.

The need or rationale behind the use of personal protective equipment is not always accepted or is sometimes questioned by personnel. The purpose of the following tests is to provide data that can be used to validate the rationale, and also to provide information for educational and training purposes. In addition, it is felt by the Safety Office that perhaps too much credence has been placed on the use of other forms of personal protective equipment not designed nor intended for specific ordnance operations, yet nonetheless, used for such.

This report summarizes the results of three separate studies involving personal protective equipment at the Naval Weapons Center (NWC). The first series of tests evaluated five types of protective eyewear to determine the effectiveness of each in a flame environment and in an explosive fragmentation environment. In the second series three types of safety clothing were tested to determine the effectiveness of each in a flame environment. The third series evaluated five types of commonly worn socks to determine the effectiveness of each in meeting present electrical conductivity standards for ordnance operations.

For ease of presentation, this report is divided into three separate sections, each covering one of the three series of tests.

## EYEWEAR TESTS

Five types of protective eyewear were tested at the explosive ordnance disposal demolition area at NWC to determine the effectiveness of each type in an explosive fragmentation environment and in a flame environment. The five types were (1) government-issued safety glasses (spectacles), (2) visitor glasses (spectacles), (3) splash goggles, (4) nitrometer mask, and (5) face shield. The manufacturers of each type of eyewear evaluated are listed in Appendix B.

## FRAGMENTATION TESTS

### Procedure

A standard U.S. Army Engineers blasting cap was placed so that it was located central to all five types of eyewear (Figure 1). The vertical orientation of the blasting cap enabled fragments resulting from an electrically initiated detonation to project out radially in all directions. This ensured high-velocity fragment impact of all protective eyewear. A distance of 18 inches (0.46 meter) between the blasting cap and each type of eyewear was chosen because it simulated personnel working at bent-arms' length to the cap, which is a common practice. The vertical center point of each eyewear type was located at the same height above ground level as the blasting cap.

Visual observations were recorded by 35-mm black and white and color still photography.

All fragmentation damage to eyewear was assessed using total impacts, deflections, embedments, and complete penetrations. To assess effectiveness, a relative protection factor was used. It was determined by adding the total number of deflections and embedments and then dividing this value by the total number of impacts. All values for each type of eyewear were then multiplied by 100 to yield a relative protection factor in percent.

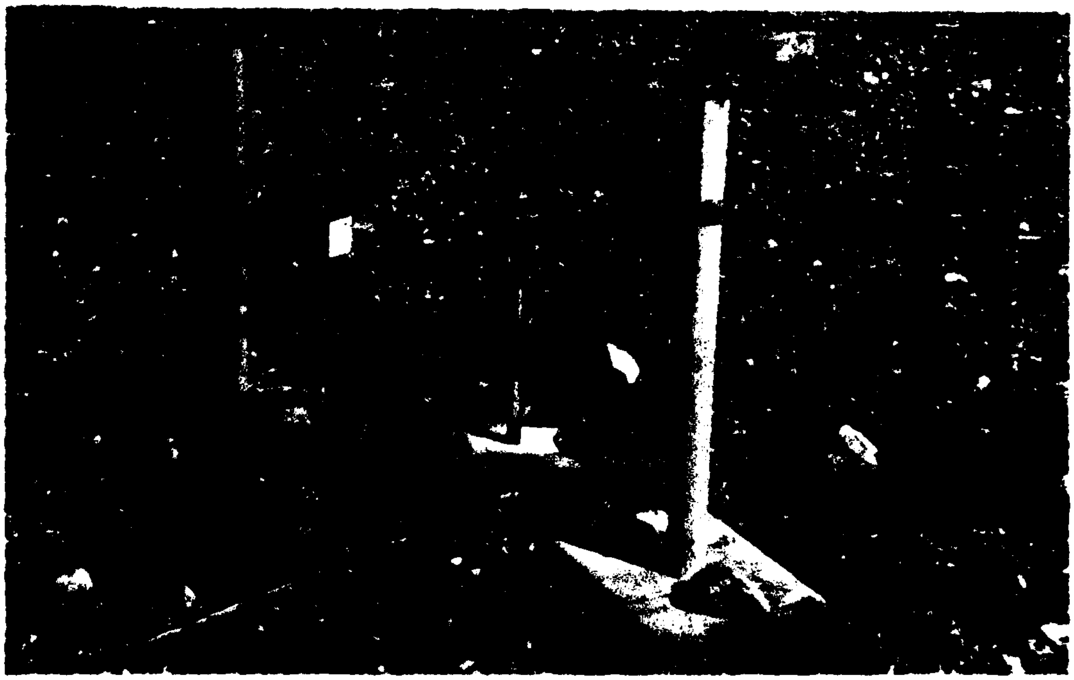

FIGURE 1. Eyewear Fragmentation Test Setup.

## Results

During the fragmentation test, some types of eyewear sustained more impacts than others, simply because of the difference in surface area exposure of the eyewear. As a consequence, more data points exist on some eyewear than others. However, sufficient impacts were sustained by all to determine relative ability to protect the eyes.

In assessing the damage, not only the cause of the damage, such as fragment deflection, embedment, and penetration, must be considered, but also the extent of each kind of damage. Lenses of eyewear with a large percentage of deflections and shallow embedments are considered most desirable for protective wear. Those with deep embedments to the very point of complete lens penetration are less desirable; and, of course, complete penetration of the lens is totally unacceptable. Results of the fragmentation tests of each type of eyewear are given in the following paragraphs and Table 1.

**Safety Glasses (Spectacles).** The test results for safety glasses are shown in Figure 2. The lenses of the glasses sustained four impacts, two of which were deflections and two of which were embedments. The relative protection factor was calculated to be 100% (see Table 1). It was somewhat unfortunate that the lenses sustained only four impacts; a higher number would have added to the validity of the conclusions.

TABLE 1. Results of Fragmentation Tests of Different Types of Eyewear.

| Eyewear type | Fragmentation | | | | Relative protection factor, %[a] |
|---|---|---|---|---|---|
| | Total impacts | Deflections | Embedments | Complete penetration | |
| Safety glasses (spectacles) .. | 4 | 2 | 2 | 0 | 100 |
| Visitor glasses (spectacles) .. | 16 | 1 | 13 | 2 | 88 |
| Splash goggles ...... | 9 | 0 | 7 | 2 | 78 |
| Nitrometer mask ....... | 41 | 13 | 14 | 14 | 66 |
| Face shield ..... | 46 | 7 | 22 | 17 | 63 |

[a] The relative protection factor is determined by adding the total number of embedments and deflections, and then dividing this value by the total number of impacts. Multiplying by 100 yields a relative protection factor in percent.

FIGURE 2. Results of Fragmentation Test of Safety Glasses.

**Visitor Glasses (Spectacles).** Figure 3 shows the test results for visitor glasses. The lenses of the glasses sustained 16 impacts, 14 of which were deflected or embedded. The relative protection factor was calculated to be 88% (see Table 1).

**Splash Goggles.** The test results for splash goggles are shown in Figure 4. Nine impacts, seven of which were embedded in the lens, were sustained by the goggles. No deflections occurred. The relative protection factor was calculated to be 78% (see Table 1).

**Face Shield Visor (Nitrometer Mask).** Figure 5 shows the results of the test of the nitrometer mask. The nitrometer mask sustained 41 impacts, 14 of which were embedments and 13 of which were deflections. The relative protection factor was 66%.

**Face Shield.** Figure 6 shows the results of the face shield test. The face shield sustained 46 impacts by high-velocity fragments. Twenty-two embedments and seven deflections occurred. The relative protection factor was found to be 63%.

## Discussion

**Safety Glasses (Spectacles).** Not surprising is the fact that the polycarbonate-composition safety glasses withstood high-velocity impact from the fragmenting blasting cap. Fifty percent of the fragments were deflected from the lens, while the other 50% were embedded in the lens. No fragments came close to penetrating the entire thickness of the lens. The inside of the lens was smooth to the

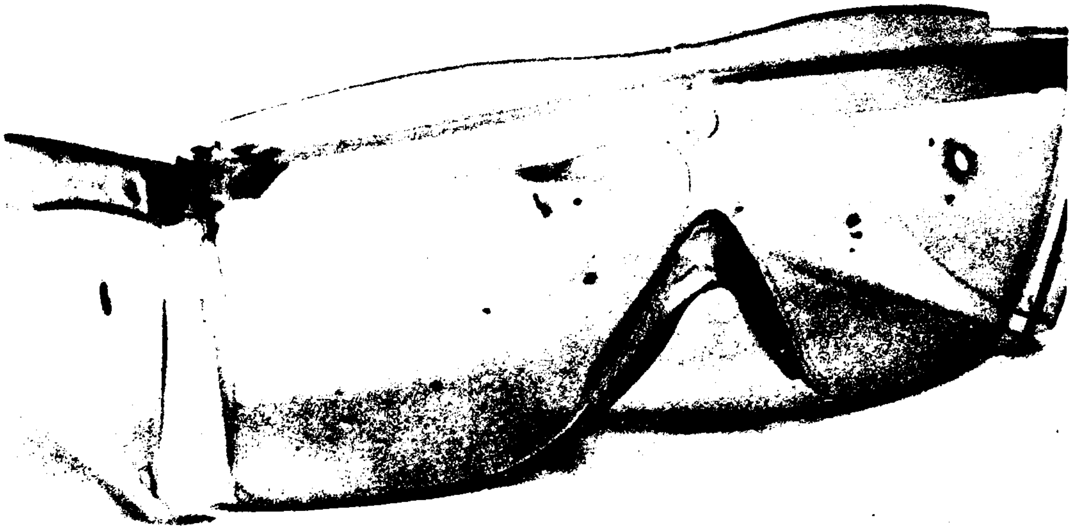

FIGURE 3. Results of Fragmentation Test of Visitor Glasses.

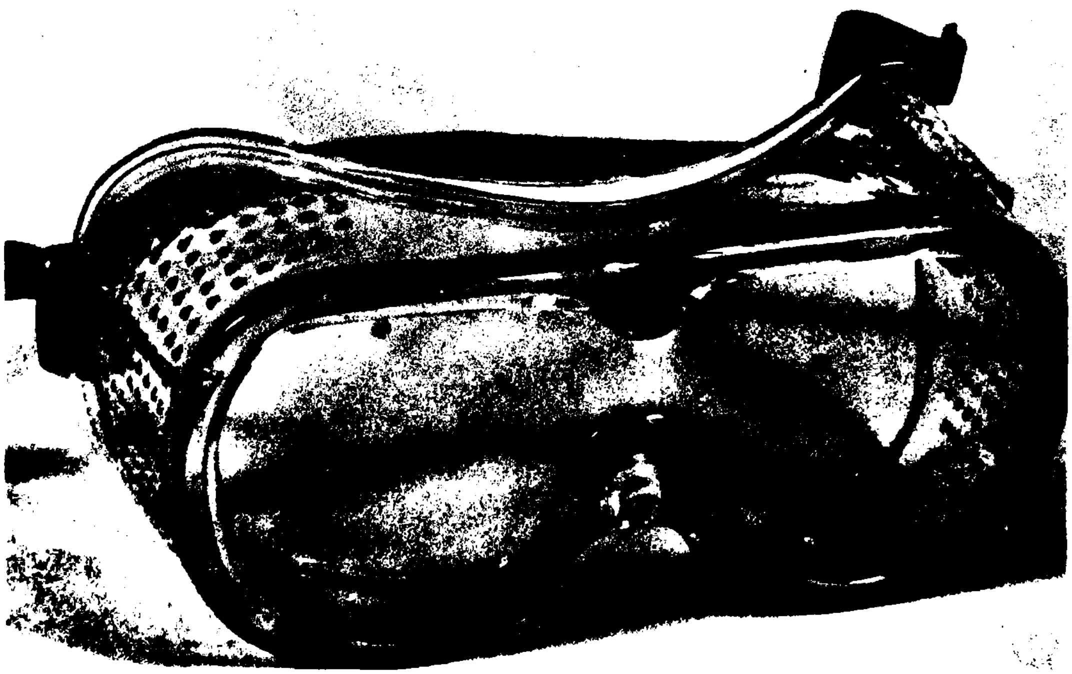

FIGURE 4. Results of Fragmentation Test of Splash Goggles.

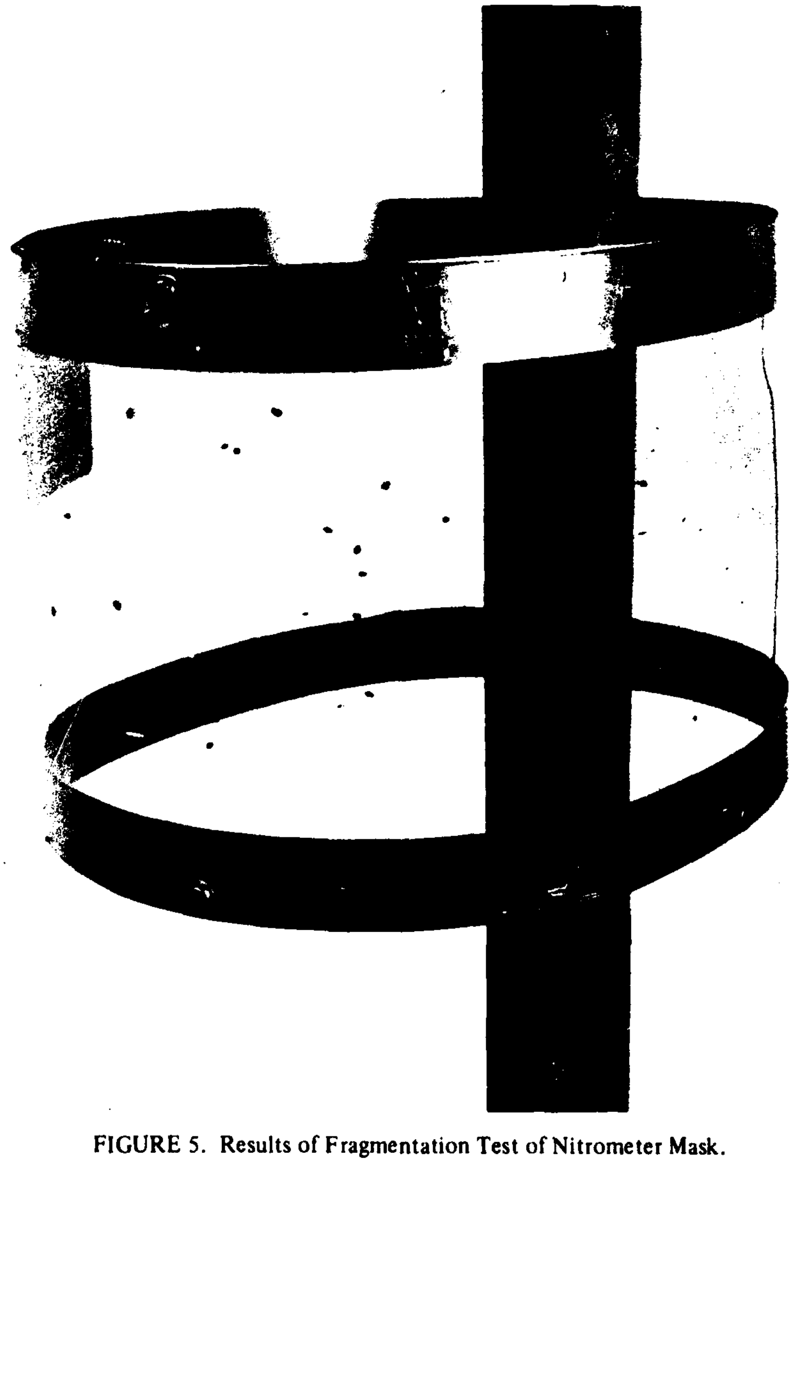

FIGURE 5. Results of Fragmentation Test of Nitrometer Mask.

FIGURE 6. Results of Fragmentation Test of Face Shield.

touch and as such indicates the appropriateness of requiring safety glasses to be worn during ordnance operations. It must be realized that the test performed simulated a small-scale ordnance mishap. It is not known whether the damage resulting from large-scale blasts with subsequent fragmentation would be attenuated sufficiently by the eyewear; however, personnel would probably not survive because of massive whole-body trauma from severe fragmentation and overpressure.

**Visitor Glasses (Spectacles).** Only two of 16 fragments actually penetrated the thickness of the polypropionate-composition lenses. This would be expected for low-velocity metal chips and filings; however, it was not expected (intuitively) for high-velocity shrapnel. The fact that all but two of the fragments were deflected or embedded indicates the relative strength of the lenses. However, the fragments that were embedded could be felt from the inside of the lens, thus indicating almost complete penetration.

It must be kept in mind that visitor glasses are intended to be worn by visitors and not by operating personnel directly involved in the hazardous work. Typically, most visitors do not get close to the operation and probably need no more protection than that provided by the visitor glasses.

Although tests were not conducted using the visitor glasses in combination with personal prescription glasses (not government-issued and approved), the test results would seem to indicate that there would be sufficient attentuation of lens damage to prevent eye injury if this combination were used.

**Splash Goggles.** Two fragments completely penetrated the polycarbonate-composition lenses, while seven were sufficiently embedded in the lenses to be felt from the inside of the glasses. Goggles typically are used in chemical processing operations where liquid splash protection is needed. The goggles were not designed nor intended primarily for high-velocity impact protection and should not be used for such protection.

**Face Shield Visor (Nitrometer Mask) and Face Shield.** Neither the nitrometer mask nor the face shield provided the protection desired in a fragmentation environment. Approximately one out of every three fragments penetrated the shield lens. Because of the 0.040-inch (1-millimeter) thickness of the shield lens, in both the nitrometer mask and the face shield, all embedded fragments could be felt from the inside. These acetate-composition shields are intended for chip and dust impact mainly generated by inert machining operations, and for liquid splash operations.

## FLAME TESTS

### Procedure

A 12-ounce (0.3-kilogram) pile of smokeless, single-based, nonperforated powder was placed in front of each type of eyewear (Figure 7). To simulate the typical angle at which personnel would be handling propellant or pyrotechnic powder on a workbench, each set of eyewear was placed 20 degrees off vertical 18 inches (0.46 meter) from the powder. Eighteen inches (0.46 meter) was picked because it was felt

FIGURE 7. Flame Test Setup Before Ignition.

that bench level to eye level separation for average-sized personnel approximated this value.

A small powder bag, ignited by an M60 fuse lighter and safety (time) fuse, initiated the propellant train, which was set up parallel to and in front of the eyewear. Wooden stands were constructed to ensure that each type of eyewear maintained its proper orientation during the test.

The wind velocity at the time of the flame test was 5- to 9-knot gusts from the southwest. Ignition took place upwind from the eyewear. All eyewear were exposed to high temperature radiation and hot combustion gases. The duration of each 12-ounce (0.3-kilogram) pile fire was about 8 seconds. The burning time of the propellant train between piles was about 5 seconds. The total duration of the test was about 60 seconds (Figure 8). Visual observations were recorded by 35-mm black and white and color still photography.

Flame damage to eyewear is assessed as none, light, moderate, heavy, or extensive; eyewear tested did not fall within the none or heavy assessment categories.

FIGURE 8. Results of Eyewear Flame Test After Ignition.

## Results

During the propellant flame test, no instrumentation was present to indicate the actual temperatures that the eyewear sustained. Also, no method was available to determine thermal conductivity of the individual eyewear. One can only assess the resultant damage due to thermal radiation and combustion gases. It is possible that some eyewear experienced a more severe test than others, but it is not considered significant since the test duration was, in a sense, an "overkill." Each type of eyewear experienced about an 8-second burn, which is much more than personnel would be subjected to, if any bodily movement away from the flame was possible. The severity of the burn to the face, eyes, and body would be dependent upon the extent and duration of flame contact and the composition of the eyewear.

**Safety Glasses (Spectacles).** The flame test results for safety glasses are shown in Figure 9. The lenses of the glasses were fogged and air-bubbled slightly; however, no melting occurred and no change in the thickness of the lenses was evident. The front of the frames and the side shields sustained moderate damage. Both side shields were partially broken from the frame. The temple portion of the frames received light damage consisting of some air bubbles. Overall, the safety glasses were given a light damage assessment (see Table 2).

FIGURE 9. Results of Flame Test of Safety Glasses.

TABLE 2. Results of Flame Tests of Different Types of Eyewear.

| Eyewear type | Flame damage[a] | | | |
|---|---|---|---|---|
| | Lens | Side shields | Front of frame | Frame temple |
| Safety glasses (spectacles) .... | Light | Moderate | Moderate | Light |
| Visitor glasses (spectacles) .... | Light | Moderate | Light | Light |
| Splash goggles ....... | Light | Light | Light | Light |
| Nitrometer mask ......... | Extensive | ... | Extensive | ... |
| Face shield ...... | Extensive | ... | Extensive | ... |

[a] Damage to eyewear is assessed as none, light, moderate, heavy, or extensive; eyewear tested did not fall within the none or heavy assessment categories.

**Visitor Glasses (Spectacles).** Figure 10 shows the results of the flame test of visitor glasses. Damage to the front and temple portions of the frames was assessed as light. The lenses of the glasses also sustained light damage. Damage to the side shields was moderate. Overall, the visitor glasses were given a light damage assessment (see Table 2).

**Splash Goggles.** The test results for the splash goggles are shown in Figure 11. Minor charring occurred on the upper front portion of the frames, with light bubbling on the side shields and lenses. No melting occurred; however, the side shields were found to be slightly distorted after the test. Overall, the splash goggles received a light damage assessment (see Table 2).

**Face Shield Visor (Nitrometer Mask).** Figure 12 shows the results of the flame test of the nitrometer mask. The acetate composition suffered severe and permanent damage due to the intense heat generated by the propellant burn. The lower half of the visor appeared to have a Saran-Wrap consistency, whereas the upper half was more solidified and had a substantial amount of permanent air bubbling. Overall, the visor was given an extensive damage assessment (see Table 2).

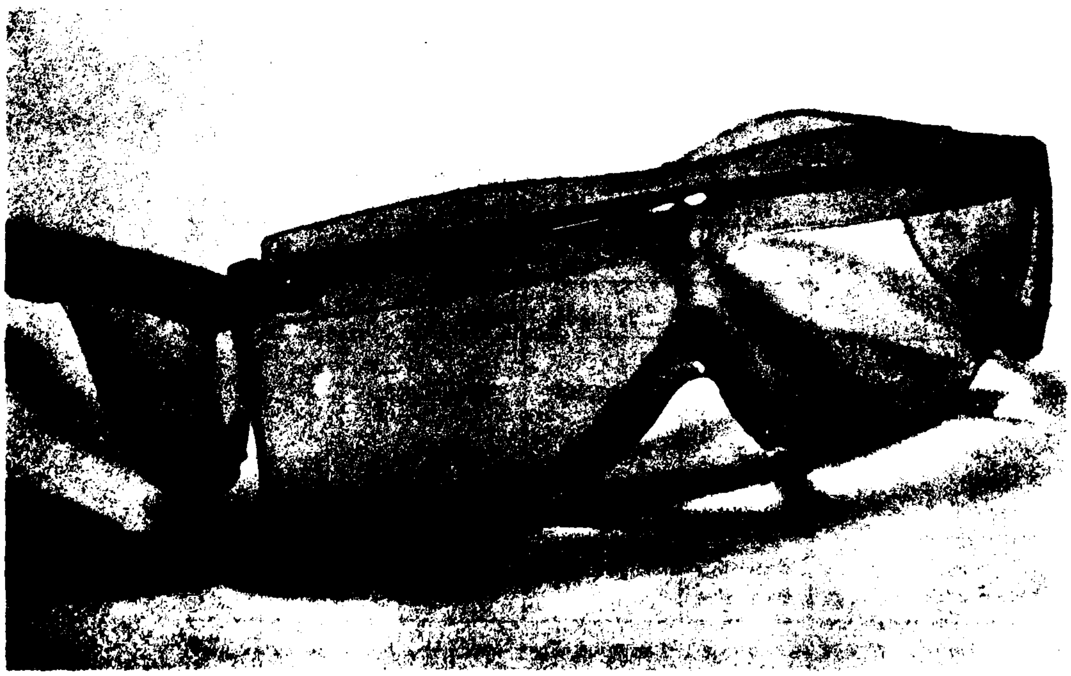

FIGURE 10. Results of Flame Test of Visitor Glasses.

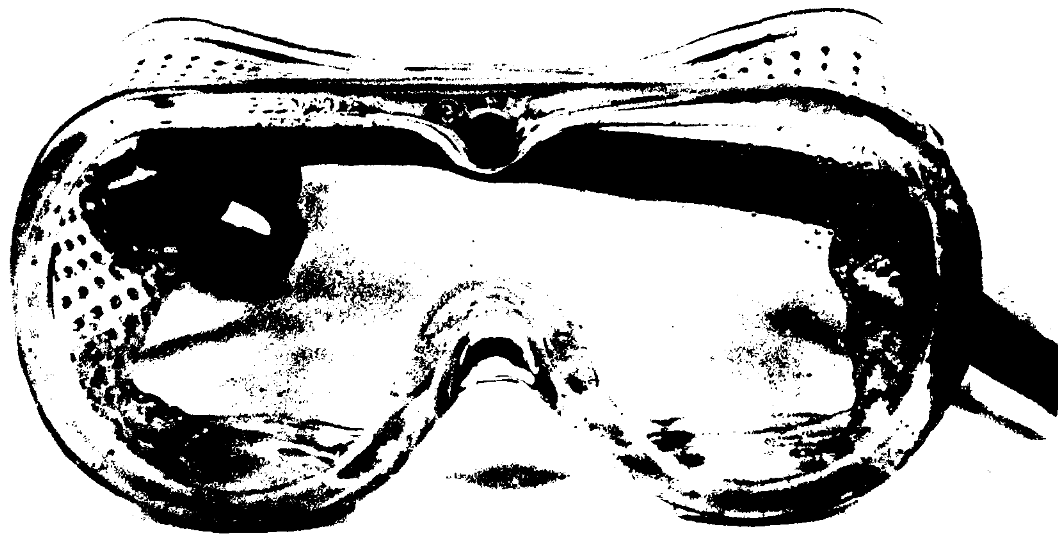

FIGURE 11. Results of Flame Test of Splash Goggles.

FIGURE 12. Results of Flame Test of Nitrometer Mask.

**Face Shield.** As was found with the nitrometer mask, the face shield also sustained extensive and permanent damage (Figure 13). Severe melting occurred throughout most portions of the acetate shield. Overall, the face shield received an extensive damage assessment (see Table 2).

## Discussion

**Safety Glasses (Spectacles).** It is not surprising that the safety glasses withstood both the thermal radiation and the hot combustion gases as a result of the propellant burn. As stated before, however, it should be realized that the test simulated a small-scale ordnance mishap and that a large-scale mishap would cause, with virtual certainty, massive whole-body trauma, even though the glasses may have attenuated damage from the fire.

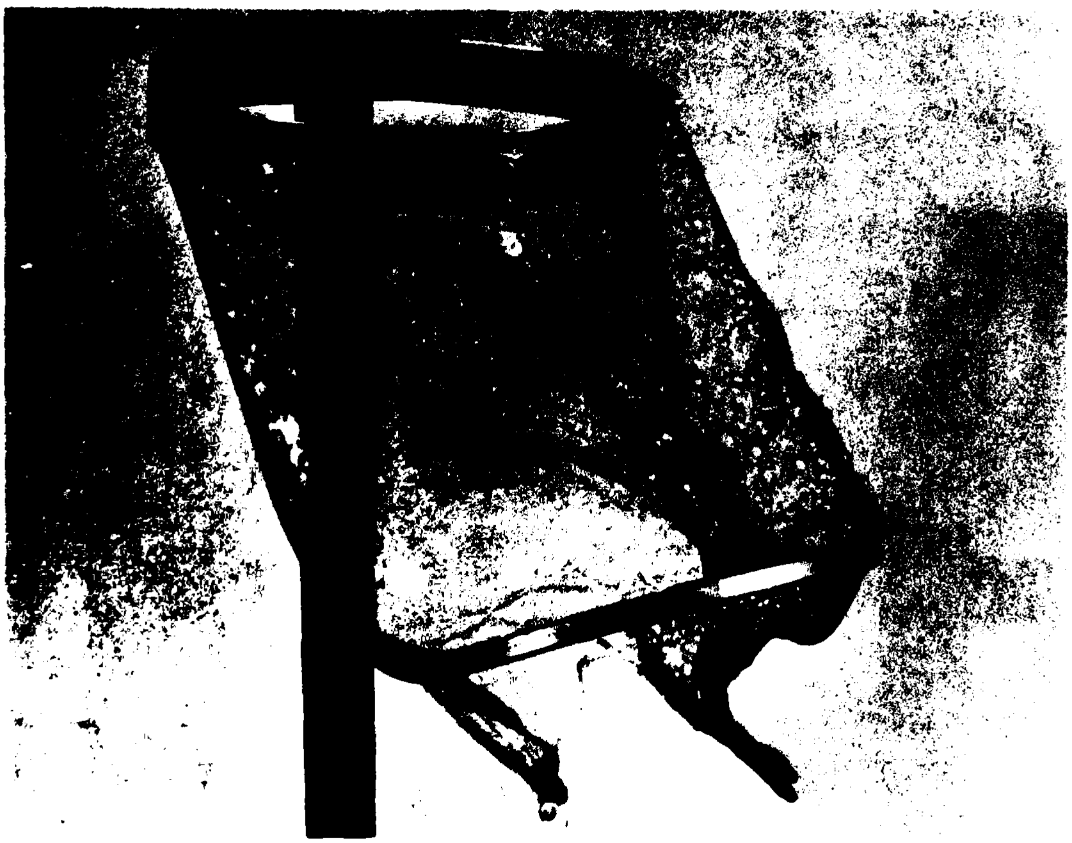

**FIGURE 13. Results of Flame Test of Face Shield.**

The duration of the test was approximately 1 minute, which included about 8 seconds of severe flame exposure to the safety glasses. Personnel would not normally be subjected to such a situation and thus the extent of damage may be looked upon as a "worst case" test situation.

**Visitor Glasses (Spectacles).** The visitor glasses held up remarkably well to the flame. The lack of damage indicates the relative heat resistance of the glasses. The temperature sustained by the glasses is not known, but results indicate that the visitor glasses experienced no more damage than the government-issued safety glasses. Visitors using this type of eyewear would more than likely receive the same amount of frontal flame protection as that provided by the safety glasses. However, temple and brow protection may not be as great. Since no melting occurred there would be no skin infection due to melted spectacle and flesh interaction.

**Splash Goggles.** Even more surprising than the assessed results of the visitor glasses were the test results of the splash goggles. Flame damage to all portions of the eyewear was assessed as light. Consequently, the goggles received the most favorable rating among the five types of eyewear tested. However, the results should be viewed with caution. The goggles were located at the end of the propellant train and may not have received the same amount of thermal exposure as the other types of eyewear. Indeed, the wooden stand supporting this eyewear seemed less charred (near the eyewear) than the other stands.

**Face Shield Visor (Nitrometer Mask) and Face Shield.** Visual observations after the test led to extensive damage assessments for these two types of eyewear. Personnel wearing such eyewear could have experienced severe burns, probable inhalation of toxic by-products from the shields, and probable skin infection from the interaction of the melted shields and flesh. Unless immediate evacuation were possible, the shields would appear to be of no value in a flame environment.

## SUMMARY OF EYEWEAR FRAGMENTATION AND FLAME TESTS

This first section of this report has described fragmentation and flame tests made to determine the effectiveness of eyewear used in ordnance operations and to indicate the hazards to personnel should they be exposed to burning materials or explosive detonations. Observation of eyewear damage as a result of the tests indicates the following:

1. The purpose of the eyewear selected and the operation in which the eyewear is to be used must always be kept in mind.

2. The apparent differences among all eyewear types tested can probably be attributed to lens thickness, lens composition, cross-linked chemicals used to facilitate lens strength and manufacturing differences of each company producing the eyewear. Purchase of any such eyewear should take into account these variables.

3. Realistically, the only eyewear providing adequate flame and light fragmentation protection is the polycarbonate safety glasses (spectacles). All other types of eyewear tested do not appear to be designed sufficiently for operator protection during explosive operations.

4. Polypropionate visitor glasses (spectacles) and polycarbonate splash goggles would appear to offer limited protection during operations with a potential for damage due to fragmentation, when worn over personal prescription glasses or government-issued safety glasses. Tests should be made to verify this assumption.

5. Polypropionate visitor glasses (spectacles) and polycarbonate splash goggles would appear to be appropriate to wear during operations with a potential flame hazard regardless of whether personal prescription or government-issued safety glasses are also worn. Tests should be made to verify this assumption.

6. The acetate nitrometer and acetate face shield masks appear to have only limited appropriateness for ordnance operations, and should only be worn in conjunction with government-issued safety glasses. The shields would appear to provide only immediate protection in a fire. Unless personnel wearing such equipment could remove themselves, or be removed, almost immediately from the fire, extensive melting of the mask material in addition to possible inhalation of smoke and toxic combustion by-products would cause serious injury. The shields do provide some attenuation of fragmentation damage, but the limited protection provided would prohibit them from being worn unless accompanied by government-issued safety glasses.

7. Discussion with several manufacturing and distributing firms indicates that the nitrometer mask and face shield could be produced using either a polycarbonate or polypropionate composition instead of the acetate material used. This would substantially increase the protection factor due to the increased strength. Fragmentation and flame tests could then be accomplished using the stronger compositions.

8. All eyewear evaluated should perform better than the results reported in other than ordnance operations, where low-velocity chips, metal filings, and dust exists (e.g., machining operations of inert components).

9. Additional tests should be made to determine the maximum amounts of explosives and propellants, maximum fragment weights, and minimum distances for which each eyewear type will offer protection.

10. Tests should be conducted using thermocouples to determine actual temperatures sustained by the eyewear, and to assist in determining thermal conductivity of such eyewear.

11. The *American National Standard Practice for Occupational and Educational Eye and Face Protection* (ANSI Z87.1), published by the American National Standards Institute, Inc., in 1968, does not concern itself with high-velocity impact situations. A deficiency in documentation concerning this area appears to exist. Only those requirements involving low-velocity impact are discussed.

## CLOTHING TESTS

Three types of safety clothing were subjected to flame tests at the China Lake Propulsion Laboratory burn area at NWC to determine the effectiveness of each type in a flame environment. The three types were (1) flame-retardant-treated cotton safety coveralls (powder uniform), (2) flame-retardant safety coveralls with street clothing

worn underneath, and (3) flame-retardant safety coveralls with a flame suit worn over the safety coveralls. A government-issued T-shirt and underpants of 100% combed cotton were worn as underclothing in all three cases.

## PROCEDURE

Three manikins were placed on one side of a table, on which was placed approximately 30 pounds (13.6 kilograms) of composite propellant shavings salvaged from processing operations and laid to a depth of 5 to 6 inches (0.13 to 0.15 meter) (Figure 14). Manikin No. 1 wore the government-issued cotton safety coveralls and cotton underclothing. The coveralls, called powder uniforms in many processing facilities, were made of tightly woven, smooth, cotton fabric treated with a diammonium phosphate or ammonium sulfamate flame-retardant solution. The coveralls, a type that requires flame-proofing after each laundering, had recently been laundered and flame-proofed.

Manikin No. 2 wore the government-issued underclothing. Over the underclothing were a cotton flannel shirt and blue denim jeans, both of which did not receive the flame-retardant treatment. Over the shirt and jeans were government-issued cotton safety coveralls. Manikin No. 3 wore a Firetex® flame suit over the government-issued safety coveralls and underclothing.

Thermocouples were placed on each manikin's breast. The breast area was chosen to ensure the most likely contact between the manikin and the clothing. A fourth thermocouple was placed unprotected by clothing on the neck of Manikin No. 1, outfitted with cotton underclothing and safety coveralls only.

Honeywell 19® recorders powered by a portable generator were used to record all thermocouple data. There were no zero time indicators on the two Honeywell recorders used. The zero time was arbitrarily chosen and is felt to be accurate only to within ±2 seconds.

To simulate body flesh, each manikin had a hot dog secured to its neck and one tied to its arm, only half of which was protected by the cotton T-shirt.

Visual observations were recorded by 35-mm color still photography.

The relative protection given by the various clothing types was evaluated by thermocouple data and visual observation.

## RESULTS

When the propellant was ignited (Figure 15), the wind was blowing away from Manikin No. 1, clothed in the underclothes and safety clothes only, and toward Manikin No. 2, wearing underclothing, street clothes, and safety clothes. Manikin No. 1 was exposed primarily to high temperature radiation, whereas Manikin No. 2 was exposed to both the radiation and the hot combustion gases. Manikin No. 2 experienced a more severe test than Manikin No. 1 as a result of this additional exposure.

FIGURE 14. Clothing Test Setup Before Propellant Ignition.

FIGURE 15. Clothing Test Propellant Ignition.

The duration of the flame was about 7 to 10 seconds, which is more than personnel would be subjected to, if any bodily movement away from the fire was possible. In this sense, the test represents an "overkill" situation.

**Safety Clothes Only**. Manikin No. 1, wearing only the government-issued cotton underclothing and safety coveralls, was protected the least, according to the data provided by the thermocouple recorders and visual observation (Figure 16). As mentioned previously, this manikin was the least exposed to fire. The cotton coveralls were charred, as was the T-shirt, and the cotton underpants were scorched. The maximum thermocouple reading was 385°F (196°C), which was reached 5 seconds after the initial temperature rise (Figure 17).

The hot dog on the neck was burned, and the hot dog on the arm was browned, except that portion underneath the T-shirt, which was unaffected.

All damage inflicted was at or above the table top height.

**Safety Clothes and Street Clothes**. Manikin No. 2 in the government-issued safety clothes with street clothes underneath was protected much more than Manikin No. 1 in the safety clothes, according to the thermocouple data (Figure 17). After 2 seconds of the initial temperature rise, a maximum of 195°F (91°C) was reached. This was the first of three noticeable rises in temperature; the next occurred about 13 seconds later and reached 220°F (104°C). Finally, 40 seconds after the propellant ignited, the street clothes ignited. The maximum rise then reached 435°F (224°C), and the street clothes burned in the midriff section of the manikin, except where the flannel shirt had been tucked into the blue jeans. The jeans themselves received some burning in the belt and pocket area. The T-shirt and coveralls were so badly burned that they disintegrated upon being touched. The underpants were virtually undamaged.

The hot dog on the neck was deeply charred. The hot dog on the arm was burned, except that portion underneath the T-shirt, which was browned. All damage inflicted was at or above table top height (Figure 18).

**Safety Clothes and Flame Suit**. Manikin No. 3, wearing the flame suit over the safety coveralls, was the most protected (see Figure 17). An initial, conspicuous temperature rise occurred about 5 seconds into the burn and reached a maximum of 125°F (52°C) after about 8 seconds. The flame suit, however, was embrittled by the fire. In the chest area where the flame suit did not protect the coveralls, light scorching occurred. The fire was able to propagate up the sleeves of the flame suit, causing extensive damage to the coverall sleeves underneath. No glove gauntlets were being worn by the manikin during the test.

The hot dog on the neck of the manikin was browned slightly in only one spot. The hot dog on the arm showed no damage. All damage inflicted was at or above table top height (Figure 19).

## DISCUSSION

The results of the clothing tests are not too surprising. More protection is certainly gained by more clothing. NAVSEA OP-5, Volume 1, *Ammunition and Explosives Ashore* (see Appendix A), indicates that street clothes may be worn under a powder uniform in operations where they are used for fire protection and to keep the

FIGURE 16. Results of Test of Government-Issued Safety Clothes and Underclothing Only.

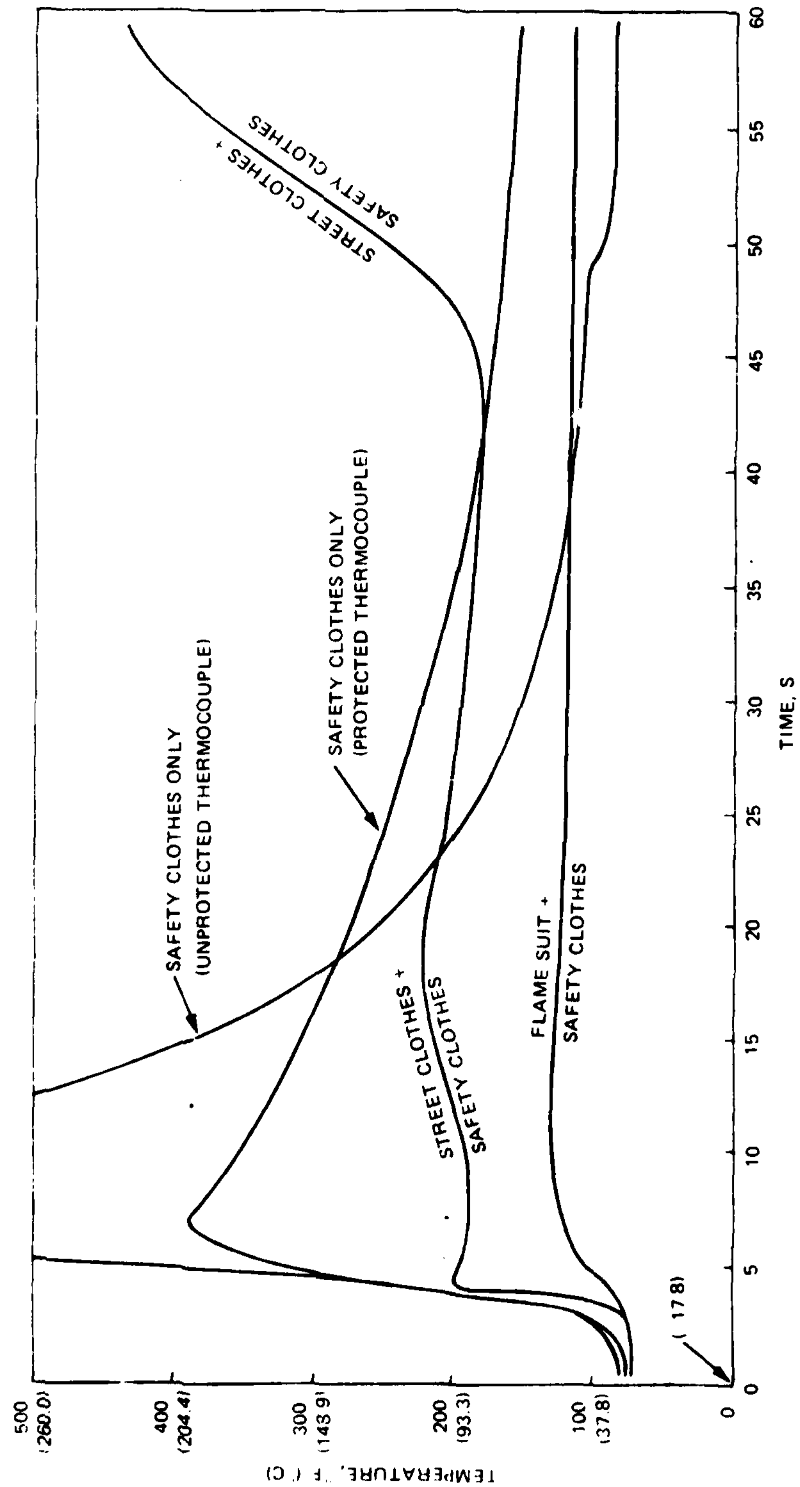


FIGURE 17. Temperature (Thermocouple Reading) Versus Time for Each Type of Safety Clothing Tested.

FIGURE 18. Results of Test of Street Clothes Plus Safety Clothes.

FIGURE 19. Results of Test of Flame Suit Plus Safety Clothes.

worker's clothes from being contaminated. The NAVSEA document, however, goes on to indicate that in operations where static electricity creates a hazard, all clothing worn under powder uniforms shall be made of cotton.

The use of the flame suit provides the best protection of the safety gear evaluated. However, again the question of static electricity must be raised. Worker mobility and comfort must also be a consideration.

Decisions must be analyzed and the risks weighed in determining the trade-off between comfort and thermal protection, static- versus nonstatic-producing clothing, and combinations thereof.

This test showed an extended time delay before the street clothing ignited. Any movement on the part of personnel away from the fire would have certainly precluded this ignition. A similar statement about the government-issued coveralls and underclothing can be made. Seven to 10 seconds is a long time to be exposed to a propellant fire. The purpose of this protective clothing is not to "fight" a fire, but to enable speedy and safe egress from one. Intuitively, all three protective outfits tested provide this capability. Of course, unprotected areas of the body, e.g., hands, face, and neck would experience severe burns without immediate evacuation. In this circumstance, additional protection would be needed.

## SUMMARY OF CLOTHING TESTS

This second section of this report has described flame tests made to determine the relative protection of safety clothing used in ordnance operations and to indicate to personnel the hazards should they be exposed to burning materials. Observations of damage to the clothing as a result of the test and conformance to current naval explosives safety regulations indicate the following:

1. All-cotton clothing -coveralls, T-shirts, underpants, and socks -must be worn in operations where the generation of static electricity would create a hazard.

2. When static electricity is of no concern and in operations where additional fire protection is needed, street clothes should be worn under a powder uniform.

3. Considering average personnel reaction time to a fire where less than massive amounts of propellant are involved and assuming ease of emergency egress, safety coveralls and all-cotton undergarments are safe and appropriate clothing to wear in environments with potential flame hazards.

4. Where flame suits are considered desirable (e.g., in areas with large quantities of explosive, sensitive propellants, etc.) they need to be of such blend and construction that static electricity can be readily dissipated. In addition, mobility is a salient factor when determining the use of such suits. Personnel comfort should also be considered. The degree of protection provided by a flame suit may be outweighed by its static-producing capabilities and its lack of mobility.

## SOCK TESTS

Five types of socks were evaluated either at the NWC Safety Office or the CT area of the Ordnance Systems Department to determine the effectiveness of each type in meeting present electrical conductivity standards for ordnance operations. The five types were (1) 100% cotton (thin), (2) 75-85% cotton/25-15% nylon, (3) 100% cotton (thick), (4) 100% nylon, and (5) 75% Orlon/25% nylon.

### PROCEDURE

Socks of the various types were issued to a number of personnel. The tests were conducted by having each person put on one kind of sock with his conductive shoes and stepping on the plates of the Safe-T-Ohm,® Model TM, shoe tester (Figure 20) used for all readings in these tests. A conductivity reading was taken immediately. After the immediate reading, additional readings were taken using the tester at specified time intervals. The tester scale range from 0 to 1,000,000 ohms is highlighted in green to indicate acceptable conductivity; the scale range above 1,000,000 ohms is highlighted in red to indicate unacceptable conductivity. This report focuses on the 2-hour testing period after the socks were donned by the test subjects.

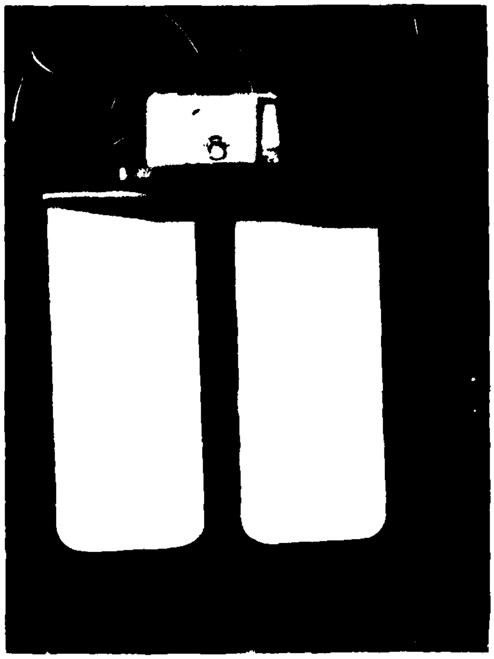

FIGURE 20. Shoe Tester Used in Sock Conductivity Tests.

During the testing period, personnel continued to perform their regularly assigned functions. This was done to simulate as nearly as possible the conditions personnel would normally experience in their work environment. Because of remote work locations, some extensive travel, and incongruous work schedules, all personnel were not tested with all sock types. In addition, not all personnel were tested at each of the specified time intervals.

## RESULTS

Table 3 shows the percentage of sock types falling within specified conductivity ranges at specified times after they were donned by personnel. To facilitate ease of discussion, K ohms will be used to indicate 1,000 ohms and M ohms to indicate 1,000,000 ohms. Appendix C gives the raw test result data.

**100% Cotton (Thin) Socks.** Immediately after personnel put on this sock type, 80% of all readings fell within the 0- to 500K-ohm range. Ten percent of the readings were greater than 500K but less than 1M. Finally, 10% of the readings were greater than 1M. After 15 minutes, 100% of the readings throughout the 2-hour evaluation period were within the 0- to 500K-ohm range.

TABLE 3. Percentage of Sock Types Falling Within Specified Conductivity Ranges at Specified Times.

| Types of socks | Range of conductivity[a] | Percentage of sock type within specified conductivity range at specified times[b] | | | | | |
|---|---|---|---|---|---|---|---|
| | | Immediately | 15 | 30 | 45 | 60 | 120 |
| 100% cotton (thin) | 0-500K | 80 | 100 | 100 | 100 | 100 | 100 |
| | >500K-<1M | 10 | ... | ... | ... | ... | ... |
| | >1M | 10 | ... | ... | ... | ... | ... |
| 75-85% cotton/ 25-15% nylon | 0-500K | 69 | 100 | 100 | 100 | 100 | 100 |
| | >500K-<1M | 8 | ... | ... | ... | ... | ... |
| | >1M | 23 | ... | ... | ... | ... | ... |
| 100% cotton (thick) | 0-500K | 29 | 71 | 100 | 100 | 100 | 100 |
| | >500K-<1M | ... | 29 | ... | ... | ... | ... |
| | >1M | 71 | ... | ... | ... | ... | ... |
| 100% nylon | 0-500K | 27 | 25 | 44.5 | 20 | 64 | 62.5 |
| | >500K-<1M | 9 | 12.5 | 11 | ... | ... | 12.5 |
| | >1M | 64 | 62.5 | 44.5 | 80 | 36 | 25 |
| 75% Orlon/ 25% nylon | 0-500K | 10 | ... | 29 | 17 | 37.5 | 37.5 |
| | >500K-<1M | 10 | 14 | ... | ... | ... | 12.5 |
| | >1M | 80 | 86 | 71 | 83 | 62.5 | 50 |

[a] K = 1,000 ohms; M = 1,000,000 ohms. No readings were exactly 1 M.
[b] Time (approximate) is minutes after subject donned socks.

**75-85% Cotton/25-15% Nylon Socks.** Immediately upon donning these socks, 69% of the tested personnel had readings that fell within the 0- to 500K-ohm range, while 23% had readings greater than 1M. As was the case with the thin cotton socks, after 15 minutes 100% of the readings throughout the 2-hour evaluation period were within the 0- to 500K-ohm range.

**100% Cotton (Thick) Socks.** With this sock type, it was found that (quite surprisingly) only 29% of the readings fell within the 0- to 500K-ohm range, while 71% of the personnel registered readings greater than 1M immediately after putting on the socks. Even after 15 minutes, 29% of those personnel wearing the sock registered readings in the >500K to <1M range. Finally, after approximately 30 minutes, all readings registered in the 0- to 500K-ohm range.

**100% Nylon Socks.** As was intuitively expected, 64% of all readings registered by personnel immediately after putting on these socks were greater than 1M. After 15 minutes, similar readings were obtained. At 30 minutes into the test, approximately 55% registered below 1M and 45% registered above 1M. A surprising reversal occurred 45 minutes after initiation of the test; 80% of the personnel wearing the nylon socks registered above 1M. This represented a 35% increase from the previous data point, rather than an expected decrease. Even after 2 hours, one-fourth of the personnel registered above the maximum allowable 1M.

**75% Orlon/25% Nylon Socks.** More than 70% of the personnel wearing socks of this content registered over 1M for at least 45 minutes. After 1 hour this percentage dropped to 62.5%. After 2 hours, readings above 1M were still being registered by 50% of the personnel wearing such socks.

## DISCUSSION

**100% Cotton (Thin) Socks.** Thin socks of 100% cotton registered the most satisfactory readings. This occurred not only immediately after personnel put on the socks, but for the entire 2-hour evaluation period. The requirement for socks of high cotton content in ordnance operations with potential electrostatic hazards is validated by the results of this test. Cotton is hygroscopic, and as such will readily absorb moisture from the atmosphere or from the feet of personnel. Moisture collected on the feet of personnel is absorbed and transmitted through the sock to the inner sole of the conductive shoe. The shoe then provides a path to ground to bleed off electrostatic charge buildup.

Internal body resistance and built-in shoe resistance keep readings from reaching unacceptably low values. Current NAVSEA explosive safety requirements allow a minimum shoe reading of 25K ohms. Several 40K-, 50K-, and 60K-ohm readings were registered during the cotton sock test; however, none approached minimum acceptability.

One somewhat disturbing aspect associated with the 100% cotton (thin) socks was the fact that 10% of the readings registered above the 1M-ohm maximum immediately after the socks were put on. For operations where the generation of static would create a hazard, regulations require socks of high cotton content. No time element is involved, yet the test data indicate that perhaps as long as 15 minutes may be needed

before maximum safety, through acceptable conductivity readings, can be achieved.

**75-85% Cotton/25-15% Nylon Socks.** All-cotton socks have become increasingly difficult to procure. Cotton socks typically have a reinforced heel and toe made of nylon. The small percentage of nylon has generally not affected the hygroscopicity of the cotton, and the test results in this report would appear to validate this. After 15 minutes, all readings registered 0 to 500K ohms. The only difference between the all-cotton (thin) socks and the cotton/nylon socks appeared to be in the readings immediately after the socks were put on. Twenty-three percent of the personnel wearing the cotton/nylon socks had readings greater than 1M, as opposed to 10% for cotton (thin) socks. Based upon the test results, 15 minutes would appear to be needed to achieve maximum acceptable conductivity.

**100% Cotton (Thick) Socks.** Thick socks of 100% cotton revealed some surprisingly unsatisfactory readings. In fact, 71% of the personnel wearing this sock type registered over 1M ohms immediately upon donning them. Only 29% fell into the acceptable range. It should be understood that the requirement for socks with high cotton content is applicable to those of thin construction only. As stated before, cotton is hygroscopic. However, permeation of moisture through thick socks takes longer than through thin socks. As a consequence, acceptable conductivity readings take longer to achieve. The test data seem to substantiate this. After 15 minutes, 71% of the readings were in the 0- to 500K-ohm range and 29% were in the >500K-<1M range. Fifteen minutes appears to be the minimum time to achieve acceptable conductivity. Thirty minutes seems most appropriate.

**100% Nylon and 75% Orlon/25% Nylon Socks.** Both types of synthetic socks worn by personnel registered entirely unsatisfactory readings. After 2 hours, 25% of the personnel wearing 100% nylon socks registered above 1M ohms. Fifty percent of the personnel wearing 75% Orlon/25% nylon socks registered above 1M ohms after the 2-hour test period. Synthetics do not absorb moisture readily. In addition, they provide good insulative effects. Both of these aspects contribute to their ability to maintain an electrical charge for extended time periods before bleed-off occurs. This could be catastrophic in those operations where electrostatic discharge may initiate loose explosives or pyrotechnic powder, or vapor-air mixtures within ignitable limits.

## VARIABLES AFFECTING CONDUCTIVITY

Several of the sock types proved to be effective for the hazardous conditions found in ordnance operations. However, many variables were found that affect the adequacy of conductivity afforded by the various types of socks. Variables that merit consideration are listed below under the general headings of shoe tester, weather conditions, shoe conditions, work conditions, and individual differences. These variables should not be considered all-inclusive.

**Shoe Tester.** The shoe tester used in this particular test, the Safe-T-Ohm, has a scale range of 0 to 1M ohms. This range is highlighted green to indicate acceptability. Above 1M ohms it is highlighted red to indicate unacceptability. However, in the red region there is no scale and, as a consequence, there is no satisfactory method to determine whether the sock readings are just slightly above acceptable conductivity or

infinitely above. It is only known that the reading is unacceptable, not the extent of the unacceptability. There is probably enough machine-error variability to make the shoe tester readings near the red-green borderline region a concern.

**Weather Conditions.** Relative humidity must be controlled to obtain reliable conductivity measurements over time. A high humidity may cause enough moisture on the socks and feet of personnel to cause most, if not all, readings, regardless of sock content, to be within acceptable limits. A low humidity may keep even thin cotton socks at unacceptable conductivity levels. Hygroscopicity is the ability to absorb moisture. If there is little moisture in the air, such as may be found in the desert winter months, hygroscopic socks will experience difficulty in moisture absorption. Consequently, readings may stay elevated for extended time periods.

In summary, cold versus warm weather conditions coupled with wet versus dry climatic conditions are variables that must be considered and controlled when evaluations of this nature are performed. This is why daily checks are important in high hazard areas (e.g., primary explosive and pyrotechnic operations), per NAVSEA explosive regulations.

**Shoe Conditions.** Ideally, the conductivity of shoes should be determined before socks are tested so that a baseline of data can be established. Shoes in good condition may initially show a conductivity reading as low as 25K ohms. Likewise, shoes in bad condition may lead to greater than 1M-ohm readings, even with 100% (thin) cotton socks.

Dirt, grime, grease, and wax are just a few of the materials that may provide sufficient insulative effects to prevent reliable and accurate conductivity readings, unless they are removed from the soles of the conductive shoes.

**Work Conditions.** Pedestrian traffic may be a crucial variable in evaluating sock conductivity. Field work that involves a great deal of activity on the part of personnel should lead to copious amounts of perspiration, and as such, adequate conductivity measurements. Likewise, office work involving a good deal of sedentary activity, and only sporadic field work, may preclude perspiration buildup and thus raise most readings above acceptability, regardless of sock content.

**Individual Differences.** Some personnel may naturally perspire regardless of their activity, while others who do active work may not perspire at all. Blood circulation plays a major part, and of course, varies with different people. Test results would seem to verify this; the same personnel generally showed higher readings on all types of socks–especially in initial readings. In summary, individuals must know their peculiarities to truly derive maximum safety through the use of socks and shoes.

## SUMMARY OF SOCK TESTS

This section has described conductivity tests made to determine the relative conductivity of various sock types that may be worn in ordnance operations and to indicate to personnel the acceptability or unacceptability of such socks. Observations of sock conductivity as a result of the tests, and conformance to current NAVSEA explosives safety regulations indicate the following:

1. Where conductive shoes are required to be worn, only lightweight socks of

high cotton content should be worn.

2. Even after donning lightweight (thin) socks of 100% cotton content, perhaps as long as 15 minutes may be needed before adequate conductivity readings can be achieved.

3. Seventy-five to 85% cotton socks, with some nylon reinforcement still meet the requirement of high cotton content and appear to provide acceptable conductivity readings after a 15-minute waiting period.

4. Thick 100% cotton socks do not appear to meet current NAVSEA conductivity requirements, and test results seem to support this. Thirty minutes may be an appropriate waiting period, after donning heavy cotton socks, before hazardous operations should commence. This long waiting period would be economically impractical.

5. Synthetic socks do not meet current conductivity requirements, and this is reinforced by the data. They do not belong in ordnance operations where electrostatic discharge is a concern.

6. Many variables, such as measuring equipment variability, weather, shoe condition, work conditions, and individual body differences, affect sock conductivity. To gain reliable information on actual sock conductivity, these variables need to be controlled.

# Appendix A

## EXCERPTS FROM NAVSEA OP-5

Excerpts from *Ammunition and Explosives Ashore Safety Regulations for Handling, Storing, Production, Renovation, and Shipping.* Volume 1, Fourth Revision (NAVSEA OP-5).

The following excerpts are from Chapter 2, "Safety Requirements, Standards, and Practices."

### 2-4.6 Protective Clothing

. . . Silk, wool, rayon, nylon, or other synthetic fiber outer or undergarments shall not be worn in any operation where the generation of static electricity would create a hazard. In operations where static electricity creates a hazard, only cotton undergarments shall be worn with powder uniforms.

### 2-4.6.1 Powder Uniforms

. . . Street clothes may be worn under a powder uniform in operations where they are used for fire protection and to keep the worker's clothes from being contaminated. In operations where static electricity creates hazard, all clothing worn under powder uniforms shall be made of cotton.

### 2-4.7 Eye Protection

Approved safety eyeglasses or eye shields shall be worn by personnel exposed to conditions which might cause eye injuries such as impact, dust, bright flame, electric welding, and splashes. The eye protection worn shall be specifically approved for the hazard involved. . .The frames of safety eyewear must not be made of highly flammable plastics.

### 2-4.9.1 Face Shields

Approved plastic face shields shall be worn by personnel exposed to flying sparks, shavings, banding and other light fragments, and hazardous splashing liquids. They shall also be worn in operations where there is a hazard from molten explosives or tar. Face shields should be kept away from excess heat and strong solvents which tend to soften and discolor them.

The following excerpts are from Chapter 4, "Electrical Requirements."

### 4-7.2.5 Conductive Shoes

b. . . . When conductive shoes are required to be worn, only lightweight socks of high cotton content will be worn.

## Appendix B

## MANUFACTURERS OF TYPES OF EYEWEAR EVALUATED

1. Safety Glasses (Spectacles)
   "Glensite" Model
   Glendale Optical Company

2. Visitors Glasses (Spectacles)
   American Safety Company

3. Splash Goggles
   "Glensite" Model
   Glendale Optical Company

4. Faceshield Visor (Nitrometer Mask)
   791315 Model
   Mine Safety Appliance Company

5. Faceshield 6300
   "Huntsman 8124" Model
   Welsh Distribution
   A. F. Johnson Company

## Appendix C

## SOCK CONDUCTIVITY TESTS RAW DATA

As stated in the main text, during the sock conductivity testing period, personnel continued to perform their regularly assigned functions. This was done to simulate as nearly as possible the conditions personnel would normally experience in their work environment. Because of remote work locations, some extensive travel, and incongruous work schedules, all personnel were not tested with all sock types. In addition, not all personnel were tested at each of the specified time intervals. The raw data resulting from the sock conductivity tests are shown in Tables C-1 through C-5.

TABLE C-1. Conductivity Measurements of Personnel Wearing 100% Cotton (Thin) Socks.

| Test subject | Conductivity[a] at specified times[b] | | | | | |
|---|---|---|---|---|---|---|
| | Immediately | 15 | 30 | 45 | 60 | 120 |
| A . . . | 150K | ... | 100K | ... | 85K | 85K |
| B . . . | 110K | ... | ... | ... | ... | 50K |
| C . . . | 150K | ... | 165K | ... | ... | 150K |
| D . . . | 300K | 90K | ... | 60K | 60K | 60K |
| E . . . | ... | ... | ... | ... | ... | ... |
| F . . . | 150K | ... | 90K | 90K | 250K | ... |
| G . . . | 350K | ... | ... | ... | 125K | 125K |
| H . . . | 110K | 40K | 40K | 40K | 40K | 40K |
| I . . . . | ... | ... | ... | ... | ... | ... |
| J . . . . | 125K | 85K | 110K | 100K | 90K | 110K |
| K . . . | 800K | 240K | 260K | 250K | 240K | 135K |
| L . . . | >1M | 365K | 200K | ... | 175K | 100K |
| M . . . | ... | ... | ... | ... | ... | ... |
| N . . . | ... | ... | ... | ... | ... | ... |

[a] K = 1,000 ohms; M = 1,000,000 ohms.
[b] Time (approximate) is minutes after subject donned socks.

TABLE C-2. Conductivity Measurements of Personnel Wearing 75-85% Cotton/25-15% Nylon Socks.

| Test subject | Conductivity[a] at specified times[b] | | | | | |
|---|---|---|---|---|---|---|
| | Immediately | 15 | 30 | 45 | 60 | 120 |
| A ... | 500K | ... | 90K | 90K | 90K | ... |
| B ... | 500K | ... | 145K | 145K | 110K | ... |
| C ... | 150K | ... | ... | 100K | 100K | 100K |
| D ... | ... | ... | ... | ... | ... | ... |
| E ... | 110K | ... | ... | 75K | 75K | ... |
| F ... | 500K | ... | ... | 145K | 145K | ... |
| G ... | >1M | ... | ... | 300K | 200K | ... |
| H ... | 90K | 65K | 40K | 40K | 40K | 40K |
| I .... | 150K | 90K | ... | 85K | ... | 75K |
| J .... | 200K | 140K | ... | 150K | ... | 175K |
| K ... | 200K | 160K | 150K | 150K | 150K | 150K |
| L ... | >1M | 400K | 250K | ... | 175K | 110K |
| M ... | >1M | 300K | 300K | ... | 260K | 175K |
| N ... | 900K | 110K | 90K | 90K | 90K | 65K |

[a] K = 1,000 ohms; M = 1,000,000 ohms.
[b] Time (approximate) is minutes after subject donned socks.

TABLE C-3. Conductivity Measurements of Personnel Wearing 100% Cotton (Thick) Socks.

| Test subject | Conductivity[a] at specified times[b] | | | | | |
|---|---|---|---|---|---|---|
| | Immediately | 15 | 30 | 45 | 60 | 120 |
| H ... | >1M | 110K | 50K | 50K | 50K | 50K |
| I .... | 250K | 90K | 75K | 75K | 75K | 65K |
| J .... | >1M | 325K | 260K | ... | 175K | 125K |
| K ... | >1M | 275K | 225K | ... | 175K | 165K |
| L ... | >1M | 900K | 325K | ... | 250K | 135K |
| M ... | >1M | 900K | 300K | ... | 250K | 200K |
| N ... | 500K | 110K | 65K | 65K | 65K | 50K |

[a] K = 1,000 ohms; M = 1,000,000 ohms.
[b] Time (approximate) is minutes after subject donned socks.

TABLE C-4. Conductivity Measurements of Personnel Wearing 100% Nylon Socks.

| Test subject | Conductivity[a] at specified times[b] | | | | | |
|---|---|---|---|---|---|---|
| | Immediately | 15 | 30 | 45 | 60 | 120 |
| A ... | 240K | 100K | 100K | ... | 90K | 100K |
| B ... | 750K | ... | 175K | ... | 250K | ... |
| C ... | ... | ... | ... | ... | 90K | ... |
| D ... | 250K | ... | ... | ... | ... | ... |
| E ... | 110K | ... | ... | ... | 100K | ... |
| F ... | ... | ... | ... | ... | ... | ... |
| G ... | ... | ... | ... | ... | ... | ... |
| H ... | >1M | >1M | 900K | ... | 50K | 40K |
| I .... | >1M | 250K | 175K | 175K | 175K | 100K |
| J .... | >1M | >1M | >1M | >1M | >1M | 475K |
| K ... | >1M | >1M | >1M | >1M | >1M | 600K |
| L ... | >1M | >1M | >1M | >1M | >1M | >1M |
| M ... | >1M | >1M | >1M | >1M | >1M | >1M |
| N ... | >1M | 900K | 375K | ... | 250K | 200K |

[a]K = 1,000 ohms; M = 1,000,000 ohms.
[b]Time (approximate) is minutes after subject donned socks.

TABLE C-5. Conductivity Measurements of Personnel Wearing 75% Orlon/25% Nylon Socks.

| Test subject | Conductivity[a] at specified times[b] | | | | | |
|---|---|---|---|---|---|---|
| | Immediately | 15 | 30 | 45 | 60 | 120 |
| A ... | >1M | ... | ... | ... | ... | ... |
| B ... | ... | ... | ... | ... | ... | ... |
| C ... | ... | ... | ... | ... | ... | ... |
| D ... | ... | ... | ... | ... | ... | ... |
| E ... | 125K | ... | ... | 75K | 100K | 100K |
| F ... | 750K | ... | ... | ... | ... | ... |
| G ... | ... | ... | ... | ... | ... | ... |
| H ... | >1M | >1M | 240K | ... | 75K | 50K |
| I .... | >1M | >1M | >1M | >1M | >1M | 575K |
| J .... | >1M | >1M | >1M | >1M | >1M | >1M |
| K ... | >1M | >1M | >1M | >1M | >1M | >1M |
| L ... | >1M | >1M | >1M | >1M | >1M | >1M |
| M ... | >1M | >1M | >1M | >1M | >1M | >1M |
| N ... | >1M | 900K | 175K | ... | 130K | 90K |

[a]K = 1,000 ohms; M = 1,000,000 ohms.
[b]Time (approximate) is minutes after subject donned socks.

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